SAR Interferometry for Geoscience applications in Greece

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Abstract

Among the remarkable advances in Remote Sensing during the last decades, spaceborne SAR Interferometry (InSAR), a relatively new remote sensing technique, originally designated to produce Digital Elevation Models (DEMs), provides a unique tool for mapping the spatial and temporal evolution of subtle surface displacements and deformation over large areas. Established value of InSAR is mainly related to subsidence, earthquake, volcano and landslide studies. InSAR recent advances, new techniques and continuity of SAR missions, along with a strong interest from the scientific and engineering community, constitute the guarantee for this field to evolve further. Primarily due to the "privilege" of having the highest seismicity in Europe and one of the highest worldwide, Greece and the broader eastern Mediterranean area exhibit an interesting environment for InSAR methods implementation. Purpose of this review paper is to summarize the research that has been carried out to date in the field of SAR Interferometry in Greece, to synthesize the results so far and to discuss the future prospects and potential applications in Geosciences.

1. Introduction

Traditional surveying techniques such as leveling, as well as GPS campaigns provide very accurate, but discrete measurements over limited areas, due to cost and feasibility constraints imposed. Among the remarkable advances in Remote Sensing during the last decades, spaceborne SAR Interferometry (InSAR), a relatively new remote sensing technique, originally designated to produce Digital Elevation Models (DEMs), provides a unique tool for mapping the spatial and temporal evolution of subtle surface displacements and deformation over large areas. This extension of the original technique, commonly referred to as Differential SAR Interferometry (DInSAR), introduces an advantage over the other geodetic methods, in that it constitutes a more revealing source of information for the geophysical processes.

Although in the past sometimes accused of being opportunistic - and indeed it is not a panacea - InSAR has demonstrated its' applicability and radar interferometry is now embraced in the arena of geodetic techniques, as its' complementary value in the field of geodesy has been recognized (Hanssen, 2003). Established value of InSAR is mainly related to subsidence, earthquake, volcano and landslide studies (Astaras, 2010). Furthermore, apart from its' contribution as a geodetic technique to be further elaborated, new applications such as meteorological interpretation of interferograms arise, improving its' value for new disciplines (Hanssen, 2001). Although still in continuous evolution, InSAR has been considered to have matured from science and engineering, in order to be integrated in a range of applications, either as a complementary information source or as the sole method of performing key measurements (Solaas, 1998). The significant contribution and the potential of InSAR techniques to Geosciences in the diachronic observation of the earth is verified by the increasing number of published papers, the attention that is drawn by internationally recognized Research Centers, Institutions, Organizations, Universities and Laboratories (e.g. ESA, NASA, CNES, DLR, CCRS), as well as by the growing number of scientists of various disciplines and engineers that get involved in SAR Interferometry (Mouratidis, 2005). InSAR processing advances, new techniques and continuity of SAR missions, along with a strong interest from the scientific and engineering community, constitute the guarantee for this field to evolve further.

SAR Interferometry basic principles and applications have been well documented (e.g. Zebker and Goldstein, 1986; Gabriel and Goldstein, 1988; Gabriel et al., 1989; Massonnet et al. 1993; Massonnet & Feigl, 1998; Bamler & Hartl, 1998). Apart from the "conventional" approach, different interferometry techniques have arisen throughout the last few years and are being further developed (Mouratidis et al., 2007); The Permanent Scatterer (PS) radar Interferometry (Ferretti et al., 2000, 2001) focuses on the identification of coherent scatterers in a series of interferograms for measuring surface displacements in the order of a few millimeters. The Small Baseline Subset (SBAS) technique (Bernardino et al., 2002) is a time series analysis approach, which uses interferograms with small baselines to minimize geometrical decorrelation at the expense of spatial resolution. Stanford Method for Persistent Scatterers (StaMPS) (Hooper et al., 2007) is a new method for PS analysis that uses spatial correlation of interferogram phase to locate pixels with low-phase variance in all terrains, while no prior knowledge of temporal variations in the deformation rate for their identification is required.

Primarily, but not exclusively, due to the "privilege" of having the highest seismicity in Europe and one of the highest worldwide, Greece and the broader eastern Mediterranean area exhibit an interesting environment for InSAR methods implementation. Purpose of this review is to summarize the research that has been carried out to date in the field of SAR Interferometry in Greece, to synthesize the results so far and to discuss the future prospects and potential applications of InSAR in Geosciences.

Prior to focusing on InSAR applications, it is essential to describe in short some relevant environmental parameters of Greece, such as physical geography, climate-vegetation and geological setting, upon which the feasibility and potential of InSAR techniques considerably depends.

2. Environmental setting of Greece

2.1. Geography - Physical Geography

Greece is located in the SE part of the Balkan Peninsula, in the Eastern Mediterranean region. Bordering with Albania, F.Y.R.O.M. and Bulgaria to the North and with Turkey to the East, Greece occupies a total land surface of approximately 132.000Km^2, extending between 34^o 15´ and 41^o 45´ northern latitude and from 19^o 30´to 29^o 45´eastern longitude (Figure 1).

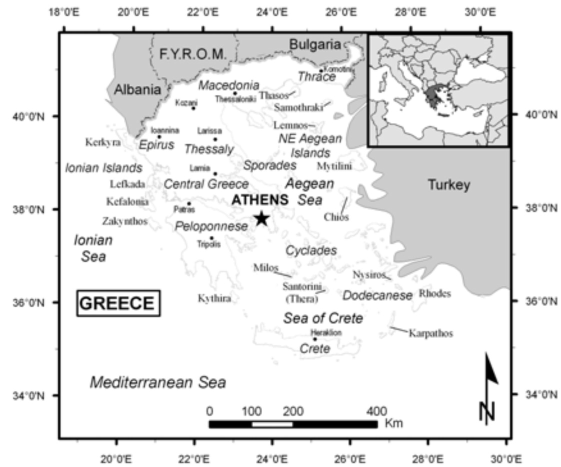

Figure 1:
Geographical location of Greece.

Greece is surrounded by the Aegean, Ionian and Libyan sea to the East, West and South respectively, with its' coastlines having a total length of about 16.000 Km, including the islands. The total number of Greek islands and islets is around 6.000, out of which only 227 are inhabited. Nevertheless, having more than 40 peaks with >2.000 m of altitude (mount Olympus; 2917 m) and a limited extent of basins and plains, Greece is overall considered as a mountainous (70%) country. Other dominating characteristics, apart from the remarkable total length of coastlines, are the fragmented relief and the numerous peninsulas that contribute significantly to an overall diverse landscape.

2.2. Climate and vegetation

The climatic conditions in Greece are generally considered as of Mediterranean type (Balafoutis, 1977), with dump winter and dry summer. Precipitation is mainly concentrated in Spring and Autumn. Nevertheless, when examined in more detail, Greece is characterized by a large variety of climatic types, spanning from the semi-dry/semi-arid climate of Crete (to the South) to the wet and cold continental character of Rodope (to the North-East), with intermediate climatic types in-between.

The vegetation of Greece is equally diverse, ranging from orange trees, olives, dates, pomegranates, figs and cotton plantations at lower elevations, whereas higher elevations are home to deciduous and evergreen forests, like those consisting of oak and pine. Concerning the islands, those of the Northern Aegean Sea, like Thassos, Samothraki and Skiathos, as well as the islands of the Ionian Sea are covered by remarkably higher vegetation than the average Greek island, in contrast with the Cyclades islands (South Aegean Sea), where vegetation is very sparse.

2.3. Geology and tectonics

The geological setting of Greece is quite complex, presenting a variety of rocks and geological formations. It mainly includes alpine and meta-alpine sedimentary and igneous formations, as well as some pre-alpine, metamorphic rocks, along with a few sedimentary and igneous rocks.

From the geotectonic perspective, through geological time Greece has always been located in a space of intense tectonic processes, between the super-continents of Laurasia and Gondwana (Mountrakis, 1985). The geotectonic evolution of Greece is thus directly related to the evolution of this broader continental margin, which is today characterized by subduction at the border of the continental lithospheric plates of Eurasia and Africa. As a result, Greece has the "privilege" of the highest seismicity in Europe and one of the highest worldwide.

3. InSAR applications in Greece

3.1. Earthquakes

The 1995 Grevena-Kozani earthquake (Mayer et. al., 1996, 1998; Hatzfeld et al., 1995; Rigo et al., 2004) and the Aigion earthquake (Bernard et al., 1997; Elias et al., 2007a) provided two good case studies for the evaluation of InSAR in earthquake-related research in Greece, with interesting results.

On the other hand, it is clearly evident that the 1999 Athens earthquake launched many more research efforts (Kontoes et al., 2000; Ganas et al., 2001; Foumelis et al., 2004, 2005, 2007; Elias et al., 2007; Papoutsis et al., 2010), because of the impact it had on the most populated area of Greece.

Other events related to seismicity that have been studied with InSAR are located in the Ionian Islands of Lefkada (Lagios et al., 2007; Ilieva et al., 2010), Zakynthos (Lagios et al., 2007) and Cephallonia (Sakas et al., 2004; Poscolieri et al., 2006; Lagios et al., 2007).

3.2. *Volcanoes*

The Greek volcanic arc of Methana - Milos - Santorini (Thera) - Nisyros and especially the island of Nisyros has been repeatedly studied with InSAR for volcanic deformation monitoring (Parcharidis & Lagios, 2001; Ganas, 2002; Sachpazi et al., 2002; Parcharidis et al., 2002; Sykioti et al., 2003; Parcharidis et al., 2004; Lagios et al., 2005a, 2005b; Gogu et al., 2006).

3.3. *Subsidence and deformation monitoring*

InSAR techniques in order to monitor or detect subsidence phenomena have been successfully implemented primarily in Athens (Raucoules et al., 2004a; Lagios et al., 2004; Parcharidis et al., 2006;) and Thessaloniki (Raucoules et al., 2004b; Raucoules et al., 2008; Mouratidis et al., 2010; Mouratidis, 2010), but also more recently in Crete (Mertikas et al., 2009).

Other deformation studies with InSAR have been conducted in Thessaly (Salvi et al., 2004; Tolomei et al., 2005; Ganas et al., 2007) and Athens (Elias et al., 2007b), whereas more targeted studies were those at Rio - Antirio bridge (Parcharidis et al., 2007), at Mornos open aqueduct (Kotsis et al., 2004) and at the Olympia archaeological site (Parcharidis et al., 2010).

3.4. *Landslides*

Landslide monitoring applications of InSAR in Greece have been so far restricted in Ioannina (Riedel & Walther, 2008), but there is great potential in several other places in Western Greece, Epirus, Peloponnesus and elsewhere.

3.5. *Digital Terrain Model generation*

Digital Terrain Model (DTM) or Digital Elevation Model (DEM) production from InSAR is a well established technique, but the existence of many competing methods of DTM production and the complexity of the actual InSAR DTM production procedure reduce its applicability.

Nevertheless, it should not be neglected that InSAR has so far provided some of the best and most complete worldwide elevation data (SRTM), while future missions like the TanDEM-X project could further improve the accuracy of InSAR DTMs.

In Greece, Digital Terrain Models from InSAR have been produced in Nisyros (Parcharidis et al., 2002) and Central Macedonia (Mouratidis, 2010).

3.6. *Geodesy*

InSAR as a complementary geodetic technique provides a challenging field of research, since the combination with GNSS and other geodetic/surveying data (e.g. leveling) is not straightforward (Hanssen, 2001). Given the geodynamical regime of the broader Eastern Mediterranean, the synergy of GNSS, InSAR and other geodetic data in Greece is worth of significant attention. Optimizing this synergy by incorporating all of the latter sources of information could be beneficial both for engineering, as well as for the various scientific applications.

3.7. Atmospheric studies

For scientists not dealing with atmospheric studies, atmospheric disturbances in InSAR processing are usually considered as undesired noise. The opposite applies for someone who is specifically interested in studying the atmosphere, hence he would consider the effects of topography, deformation or orbit errors in the phase information of SAR signal, as noise.

In this context, the potential of InSAR methodology in meteorological research has been well recognized and meteorological interpretation of interferograms is believed to improve the value of radar Interferometry for a new discipline (Hanssen, 2001). Thus, atmospheric studies with InSAR could find interesting applications in Greece, like in any other part of the world.

4. Conclusions and future prospects

Although SAR Interferometry is considered to be a mature technique from science and engineering, it seems that there is still plenty of room for improvements, both in the engineering and applications domain. As new techniques are being implemented and tested, one thing is clear, that the full potential of InSAR is yet far from being fully exploited.

As far as Greece is concerned, it presents neither the most or the least favourable environment for InSAR implementation. In particular, applications so far have shown that the applicability of conventional InSAR techniques is subjected to limitations imposed mainly by the loss of coherence in vegetated areas. These unfavourable conditions make the implementation of InSAR more challenging, even for small temporal baselines, but in any case not impossible.

With the current and future series of higher resolution, shorter repeat cycle, multi-polarization and different frequency (X, C, L bands) SAR data (ALOS/PALSAR, TerraSAR-X, CosmoSkymed, Radarsat-2, Sentinel-1, etc) new potentials for InSAR applications arise.

Nevertheless, considering only ERS and ENVISAT acquisitions, there is still a wealth of available archived data that have not yet been exploited; hence a lot of work remains to be done. The above data, combined with a variety of interesting geophysical processes that take place in Greece, constitute a solid foundation for justifying the continuity and intensification of InSAR research in the region. In this context, collaborations of researchers having solid experience in InSAR are strongly encouraged in order to ameliorate our knowledge for the benefit of Geoscience and Engineering disciplines.

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